DOCUMENT RESUME

ED 385 201 HE 028 467

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TITLE Basic Guidelines for Brain-Compatible Classrooms: Theory to Praxis.
PUB DATE Apr 95
NOTE 13p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, April 18-22, 1995).
PUB TYPE Information Analyses (070) -- Speeches/Conference Papers (150)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Cognitive Processes; *Cognitive Psychology; Cognitive Structures; Educational Philosophy; Educational Psychology; Elementary Secondary Education; Higher Education; *Influences; *Learning Processes; Montessori Method; Neurology; *Neuropsychology; Student Behavior; Student Evaluation; Student Motivation; *Teaching Methods
IDENTIFIERS Dewey (John); *Neural Networks; Neurosciences

ABSTRACT

This paper reviews recent findings in the field of neuroscience that may have a direct impact on specific methodologies and practices in education. It focuses on five concepts from neuroscience: (1) the mind-brain processes symbolic information; (2) neurons are imbued with an epistemic hunger and the mind-brain with a cognitive imperative to learn and form neural networks; (3) learning is a process of forming novel neural networks through the recognition of patterns; (4) novel neural networks can only form as relevant extensions of or alterations to previously existing neural networks; and (5) there is, for each mind-brain, an optimal level tension for the facilitation of neural network formation. The paper argues that educators should take into account that all thinking is abstract, that they should build upon the incessant natural desire for knowledge, that students be allowed to recognize patterns for themselves, that instructors contextualize information so as to provide multiple perspectives, and that instructors should employ challenging but not overwhelming instructional and evaluation methods that allow students to find their best tension level of learning. The paper also relates these ideas to the educational philosophy and methods of John Dewey and Maria Montessori. (Contains 21 references.) (MDM)

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ED 385 201

Basic Guidelines for Brain-Compatible Classrooms: Theory to Praxis

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Introduction

The quickly advancing field of neuroscience does not provide mystic, unique and unfathomable revelation into the functioning of the human mind-brain. And, despite some of our hopes as educators, it will not provide a magical new pedagogy for our classrooms. Nonetheless, recent findings of brain science are significant to educators because neuroscience can clarify the importance of certain methodologies and philosophies of education. In many ways, recent findings of neuroscience furnish new justifications for and buttressing of some well-known, but currently out of fashion educational practices such as those proposed by Maria Montessori and John Dewey (Montessori, 1912 and Dewey, 1966). My purpose in this discussion is to bring some of these findings to your attention, and interpret them in light of their importance for educators and classroom praxis. Before we proceed with our investigation of neuroscience's relevance for classroom teachers though, I need to explain some terms and thereby provide a basis for what will follow.

Mind-Brain: the Term and its Metaphors

Our western, traditional Cartesian perspective has long split the mind and brain into two artificially separate concepts (Chappell, 1981). The *brain* has been limited to describing the physiological aspects of mental life, while the *mind* has been limited to an exploration of a *self* believed to be separate from any physical context. I assert that it is better to avoid this reductionism and rejoin these two terms through the use of the concept *mind-brain*. This is the biogenetic structuralist perspective of neuroscience. This perspective avoids the error of reductionism by understanding that the *mind* and the *brain* refer to two aspects of the same thing, the *mind-brain* (Laughlin, McManus, & d'Aquili, 1990). Using the term mind-brain will keep us cognizant of the interrelationship of consciousness and physiology such that mind-brain will be recognized as a single unity.

Our mind-brains are amazing organs. In each era, our civilization finds new and more complex metaphors for explaining the workings of our mind-brains. For example, as

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we entered the machine age, Descartes helped explain our thinking by using the metaphor of a machine with a complex system of interlocking gears, the turning of which generated our thoughts. Today, most explanations of the mind-brain involve computer metaphors. I can not be certain what new technology lies on the horizon of discovery, nevertheless, I can safely assume that the most complex of these will produce new metaphorical language for explaining our mind-brains. For now though, despite its inadequacies, the language of computer science remains the dominant metaphor for explaining the working of our mind-brain.

Neuroscience literature is filled with references to the parallel processing of the brain, the input and output of information, and references to "hard wired" or programmed aspects of brain function (Dennett, 1991, and Harvey, 1994). Nonetheless, this metaphor is still inadequate, for in addition to maintaining basic bodily functions, the human mind-brain processes massive amounts of information at a rate faster than any computer yet created. The sum total of all of this processed information yields a *self*, a conscious being. (Eccles, 1994) Despite the temptation of the computational metaphor, I am certain that we all would be reluctant to reduce our unpredictable, spontaneous *self* or *being* to a deterministic program.

Basics of Neuroscience

Recent findings of neuroscience research have revealed some relatively certain "truths" about mind-brain function. For example, we know that the basic unit of the mind-brain is the *neuron*. Each neuron serves as variable switch which is triggered by electrochemical impulses from other neurons (Churchland, 1989). Depending on the strength and type of incoming signals, each neuron 'fires' or 'doesn't fire' at different levels. This firing is, in turn, received and interpreted by other neurons which also may 'fire' or 'not fire.' Thus, individual firings of neurons link up to form great chain reactions of neural firings through which the brain operates, interprets the world, and forms the physical basis for our *self*.

More formally known as *neural networks*, these chain reactions of neural firings constitute mind-brain functioning: the physiological aspects of the activities we name as conscious and non-conscious, subconscious or unconscious, are all controlled in this manner. In this way, neural networks are absolutely fundamental to thought (Liston, 1994).

From this basic description of neural networks, we can begin to explore the points at which contemporary brain science can contribute to educators' understanding of our profession.

Five Relevant Points

There are five ideas from neuroscience that I find especially relevant for educators:

1) the mind-brain processes *symbolic* information,
2) neurons are imbued with an *epistemic hunger* and the mind-brain with a *cognitive imperative* to learn and form neural networks,
3) learning is the process of *forming novel neural networks* through the *recognition of patterns*,
4) novel neural networks can only form as *relevant extensions* of or *alterations* to previously existing neural networks, and
5) there is, for each mind-brain, an *optimal tension level* for the facilitation of neural network formation.

The Mind-Brain as Symbolic Information Processor

First, we must understand that the mind-brain processes symbolic information. Stimulus that the mind-brain receives as input is received and transmitted in the form of electrochemical impulses across neural networks which symbolize the external world (Laughlin, McManus, & d'Aquili, 1990). Thus, for example, each of our mind-brains likely has a neural network for the idea of a *chair*. This neural network mentally symbolizes the concept of 'an object that can be sat upon' and becomes active, for example, when we see or think of a chair, or when we wish to sit down.

Human "experience is [at base] symbolic because the system that generates the experience processes only symbolic material" (This processing is known as *homeomorphogenesis*) (Laughlin, McManus, & d'Aquili, 1990, p. 245). This is a significant reminder that the world we encounter is a world of symbols. We understand our world through the interpretations of these symbols. Yet, symbols are relevant only within a context. This means that our mind-brain seeks relevant, contextualized meanings for symbols. Through this process, our mind-brain receives stimuli symbolically and translates these into meaningful symbolic interpretations of our worlds.

Educators often complain that their students do not engage in critical thinking and never approach the higher, more abstract levels of Bloom's taxonomy of cognitive skills.

However, neuroscience demonstrates that the entire process of thinking itself is abstract and that symbols are used by everyone.

Epistemic Hunger and the Cognitive Imperative

The second basic point of relevance for educators that emerges from neuroscience is that neurons are imbued with an *epistemic hunger*, a desire to know, to seek out relationships with each other and form neural networks. As their most basic genetic propensity, neurons continuously attempt to form meaningful, symbolic networks with other neurons. According to Laughlin and co-authors, this incessant epistemic hunger at the level of the neurons, when magnified to the larger, holistic scale of mind-brain functioning, becomes a *cognitive imperative* to learn through the building of neural networks. The cognitive imperative is the mind-brain's constant and "fundamental drive ... to complete the cycle from stimulus input to [symbolic] models and [finally to the] appropriate action related to the stimulus" (Laughlin, McManus, & d'Aquili, 1990, p. 166). The symbolic models formed are neural networks, the results of learning. And, as Leslie Hart reminds us, "the learning process is incessant" (Hart, 1983, p. 16). It is incessant because we are constantly driven to seek out new information and stimuli that will allow to the formation of novel neural networks to symbolize and explain our worlds.

On the basis of research from the field of linguistics, Steven Pinker has hypothesized that there may even be specific learning modules within the mind-brain, a suggestion that meshes well with our understanding of neural networks. In this model, individual mind-brain modules (which would resemble grand neural networks) would be specifically devoted to learning, for example, language or "intuitive biology" or habitat selection, to name a few (Pinker, 1994). Each learning module or grand neural network within the mind-brain would have a singular imperative to screen all the various stimulus input for data relevant to its area of responsibility and use that data to augment its symbolic understanding of a particular aspect of our world.

Because of epistemic hunger and the cognitive imperative, students arrive in our classrooms driven to learn and fully capable of complex thinking. In fact, our students enter the world with a hunger to know. Their desire and impulse to continuously identify and classify connections between stimuli has been "wired" into their mind-brains. The unending multitudes of "why" questions posed by children when presented with a novel idea or object attests to this. We need to keep this epistemic hunger in the foreground of our endeavors to educate our students. Motivation should not be a problem in our

classrooms. Our job as teachers should be to present challenges that will engage the interest and stimulate the processing structures of our students (Caine & Caine, 1991).

Recognizing Patterns

We are "wired" to constantly receive innumerable stimuli and to process them into output. Our mind-brain accomplishes this by recognizing patterns within stimuli past and present and generating responses to our world on the basis of these patterns. In "real life" outside the classroom, learners are continually extracting patterns from the confusion of massive stimuli. The brain's area of expertise is detecting patterns within huge amounts of input and relating various kinds of stimuli to one another. For example, we can distinguish a particular bird call from the cacophony of the rain forest or even recognize a single familiar face in a sea of people across a football stadium. Moreover, using the same stimuli from a football game, we can distinguish many other patterns: home team versus visitors, band from spectators, or children from adults.

We, as educators, should take advantage of this genetically programmed operation to encourage learning rather force our students to memorize or accept connections with very little stimuli. The mind-brain is incredibly powerful at gleaning relevant patterns from massive input, but that ability is wasted and 'natural' learning stymied without multitudes of stimuli. Too often in our classrooms, we become excessively concerned with staying 'on task' in order to focus attention on a single speaker and present distillations of the "facts" without any accompanying information. Mistakenly, we anticipate the conclusions for our students in an effort to clarify the "important" information for them. We often preset one answer, one interpretation of the information, when many interpretations are possible. In these ways, instead of working with the operation of our students' brains, we often work against their functioning. Within this pedagogy, there is no need for students to engage in pattern detection, for the interpretations have already been made and the challenges already removed. It seems that an understanding of brain function indicates we would better enable students to learn if we presented masses of information and allowed them to detect patterns based upon the unique neural networks already in their mind-brains.

New Neural Networks Must Attach to Relevant Existing Networks

The fourth concept from neuroscience is perhaps the most important. Speaking metaphorically, you cannot construct a building without a foundation underneath, nor can

you hook up a train without a first connection. All things must have a starting point, and so it is with neural networks. Findings from brain science show that novel neural networks do not last unless they find connection to a pre-existing network. The new idea or knowledge symbolized by the new network needs a 'hook' to hang upon, a point of entry to the pre-existing structure of the mind-brain.

Thus, during the learning process, novel neural networks must evolve as extensions of or alternatives to previously existing neural networks. This guideline reminds us of the truth of the aphorism that all learning is based on previous learning (Hart, 1983, and Calvin, 1990). Note that this does not mean that students must follow a 'scope and sequence,' taking pre-algebra before geometry and reading *Romeo and Juliet* before *Hamlet*. Instead, it means that unless we relate new information to a pre-existing area of student interest and knowledge, there will be no point of entry; no previously established neural networks onto which students can connect or "hang" new extensions. We may cause previously unconnected neurons to meet for an instant, but if we do not link these new connections with more established neural networks, the new connections will be very short-lived and the knowledge they symbolize will be lost. For this reason, information must be somehow relevant to the learner and thus 'attachable' to an existing network in order to be learned and absorbed.

Each learner's collection of neural networks is unique, and therefore, each student must find their own perspective relating new ideas to areas of personal interest. Each will find different aspects of the new knowledge relevant and thereby find their own 'hook' upon which to hang the newly forming neural network. For example, the point of entry for one student studying the history of suffrage in the United States would almost certainly be different from that of her classmate. One might have a keen interest in protest movements while the other might find her point of entry through her great-grandmother's memories of voting for the first time. Therefore, the first might attach the new 'suffrage' neural network to a pre-existing one about the civil rights movement while the second might hook onto her long-standing network about her great-grandmother. Both would be receiving similar stimuli, but each would extract or recognize different, yet equally valid, patterns based upon their own pre-existing neural networks.

Thus, what is relevant or pertinent in a lesson is not determined by the curriculum or the teacher, but by the learner and his or her own unique neural networks. But, in order for this individualized formation of networks to be possible the new information must be presented in a rich context that will allow students to find their own unique

"hooks." Often however we, as teachers, make the mistake of decontextualizing information. We divide the curriculum up into artificial subjects such as vocabulary, grammar, math, science, history and social studies, each with its own independent structure. These structures serve to isolate the information presented in schools, and thereby decrease its relevance to the learner. Without a multitude of "points of entry" to allow the students to link up with their pre-existing neural networks, students and teachers have greatly reduced the options for retaining and applying new knowledge. No wonder we have students who memorize definitions of justice and democracy, but have no understanding of the importance of these terms in the history of the United States.

When students enter our classrooms, even for the first time, they come with an already established system of neural networks. This system should be allowed to facilitate our efforts to educate our students. Our task as educators is to establish links between previously existing neural networks and the new information we are presenting to our students. The possibilities of generating these linkages are increased through creating diverse and textured classroom environments. Allowing students to experience a wide range of methods and materials will encourage learning. When students have the opportunity to approach a topic from their own unique perspective, their chance of hooking up with pre-existing neural networks is tremendously enhanced and their odds of making that knowledge their own directly increased.

Optimal Tension

This brings us to the fifth and final finding from neuroscience that I find pertinent for educators: for each mind-brain there is an optimal level of tension or interest where the formation of neural networks is best facilitated (Churchland, 1989). The learner must be interested in the material and his or her epistemic hunger must be brought into play in order for learning to occur.

For this reason, the learning environment must be reasonably challenging to maintain a high level of interest on the part of the learner. If the level of challenge is too low, the learner will be distracted from the class material, and will be drawn to more interesting ideas and concepts. However, the level of challenge must also not be brought to the level of threat. Many students suffer from "test anxiety." They experience what Renate and Geoffrey Caine refer to as "downshifting." (Caine and Caine, 1991) Under ordinary circumstances our students are utilizing their most advanced part of the human mind-brain, the cerebrum, while in our classrooms. However, when students feel

threatened, their less-advanced brainstem, limbic system and cerebellum become dominant, and our students experience "fight or flight response." The electrochemical reaction brought on by perceived threat causes inhibition of neural network formation. (Gazzaniga, 1988) The racing pulse rates, shortness of breath, and sweaty palms of our students attest to the high level of anxiety they are experiencing. As a consequence, they often fail the test.

Thus, our testing often reveals little more than the level of comfort any particular student feels with taking a test. (Hart, 1983) One of the most important lessons we can learn from neuroscience research is that testing is often a reflection not of how much a student does or does not know, but a reflection of his or her ability to perform well in a testing situation. Students who have positive experiences with testing will be more relaxed than students who have negative experiences. Thus, we, as educators must find less stressful methods of evaluating what our students know. Perhaps less stressful methods of evaluation such as class discussions or writing assignments would be more accurate representations of what our students learned.

The Five Guidelines for Classroom Praxis and the Middle Grades Concept

The five points from recent neuroscience research that I have reviewed imply certain recommendations for classroom praxis including: 1) that all thinking and learning be recognized as abstract, 2) that we welcome and build upon the incessant natural desire for knowledge that our students demonstrate in 'why' questions, 3) that we allow students the opportunity to recognize patterns for themselves rather than distilling information for them, 4) that we contextualize the information we present in the classroom so as to provide multiple perspectives upon the material, and 5) that we pursue challenging and yet not overwhelming instructional and evaluation methods that allow individuals to find their best tension level for learning.

These guidelines and recommendations are not new nor unique to neuroscience. For example, they have much currency, although unfortunately limited implementation, today in the middle school movement. Some elements of the middle school concept include:

1) James Beane's Personal and Social Concerns 'Intersections Model' for Middle School Curriculum,
2) Student-Centered Exploratory Learning in a Rich Environment,
3) Interdisciplinary Curriculum through Team Planning and Teaching, and

4) Authentic and Portfolio Evaluation (Beane, 1990, George, 1992 and Stevenson, 1992).

These elements, although they were not developed as responses to neuroscience, answer many of the guidelines developed above.

The middle school concept seeks to develop a curriculum which is focused on the life cycle stage of the adolescent learner. This approach encourages integrated courses in which the curriculum is planned and studied in the context of the issues these students confront in their daily lives, for example, independence versus interdependence. The development of a self-identity separate from everyone else, especially parents, is recognized as an essential aspect of the curriculum for adolescents. Also recognized is the often contradictory desire of young adults to "fit in." The middle school concept establishes a brain-compatible environment where traditional subject matter is addressed within the extremely relevant context of the students' real life concerns about being independent while 'fitting in.'

Because of its emphasis on the development of the learner, exploratory learning and authentic evaluation, and its focus on an integrated curriculum addressing issues of relevance to the learner, I view the middle school concept as an example of a brain-compatible approach to curriculum.

Philosophical Underpinnings from Maria Montessori and John Dewey

The guidelines I have presented extend beyond the contemporary middle grades concept though. As I noted in my introduction, the findings of contemporary brain science and the methodologies they imply provide new support for existing educational perspectives. In fact, they find antecedents in the work of several of our most important educational philosophers. For example, the work of Maria Montessori and John Dewey exemplify positions which are supported by neuroscience research.

The Montessori method can be said to be no method at all. As Montessori states: "There was no method to be seen, what was seen was the child ... The first thing to be done, therefore, is to discover the true nature of a child and then assist him in his normal development." (Montessori in Hainstock, 1986, p. 65) Instead of focusing on the subject matter, the focus remains on the child: "A child is a discoverer. He is an amorphous, splendid being in search of his own proper form...The importance of physical activity or movement in the psychic development should be emphasized." (Montessori in Hainstock, 1986, p. 64) Montessori based her method in scientific inquiry. The principal role of the

teacher is as an observer. The teacher is to watch the students, study their behaviors and determine their needs. The teacher simply "opens the door" to learning. Motivation must be intrinsic, based on the needs and interests of the child. The learning environment is a "prepared environment" in which the "absorbent mind" of the child is stimulated and allowed to develop naturally. (Hainstock, 1986)

Montessori's position anticipates recent neuroscience research in that the emphasis is placed on the learner. Her assumption of a natural search by the child to learn (the absorbent mind) recalls the cognitive imperative revealed through neuroscience. The activity of learning is recognized by both as part of the ordinary, incessant activities of children. Furthermore, like neuroscience, Montessori insists that the total environment of the child must be taken into account.

The philosophical position of John Dewey is also given renewed support through neuroscience research. In Dewey's work, the learner and their community are of central importance. For Dewey, learning must be intrinsically motivated and it must be relevant to the learner. The best way to make learning relevant is for learners to engage in projects that are useful and of value to the learner and the larger community. As Dewey explains: "The deeper and more intimate educative formation of disposition comes, without conscious intent, as the young gradually partake of the activities of the various groups to which they may belong." (Dewey, 1966, p. 22)

Dewey critiques much of contemporary education as "unreal," or irrelevant, for the learner. He claims that the school setting and atmosphere tend to discredit the overall importance of education. "There can be no doubt that a peculiar artificiality attaches to much of what is learned in schools. It can hardly be said that many students consciously think of the subject matter as unreal; but it assuredly does not possess for them the kind of reality which the subject matter of their vital experiences possesses." (Dewey, 1966, p. 161)

Dewey's proposals to address these difficulties are supported through neuroscience research. First, the learner must be primary to the process. His or her development and the environment of learning must be taken into account. Also, learning must be made "real," that is, given importance and relevance to the learner and the community of which the learner is a part.

Conclusion

As we have seen, it seems that neuroscience provides scientific evidence of justification for the implementation of child-centered approaches to teaching and learning. The research shows that the mind-brain is an organ which represents our "self." Through the functioning of the mind-brain, we process symbolic information in order to extrapolate meaning. Meaning is formed through the detection of patterns which, in turn, generate neural networks. These patterns and neural networks become relevant because they constitute the meaning that we make of our lives and our worlds.

As educators, we need to keep our attention on the functioning of our learner's mind-brains. We must remember that 'higher level' thinking and the processing of symbolic information is constantly taking place in our students' mind-brains. We need to draw upon our student's innate desire to learn, their 'cognitive imperative' to know. We should not forget that our students learn by generating new neural networks, a process that is best facilitated by simply allowing our students to discover their own points of relevancy within a vast array of information. Finally, we can also benefit our students by decreasing counterproductive tension in our classrooms. These neuroscience-based guidelines for brain-compatible classrooms are in many ways not new. However, I believe that neuroscience reinforces the already solid grounding for a child centered curriculum such as I have discussed.

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